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Accompanying paper to the report on

The effectiveness of the planned Międzyodrze floodplain polder and the watercourse flow regulation concept to improve the flood protection in the Lower Odra", commissioned by Deutscher Naturschutzring".

The Odra river is an example of a river strongly transformed by human, where, in addition to natural processes of sediment transport and river bed formation, there are phenomena used in the hydrotechnical construction to regulate the river. For this reason, the understanding of the river bed processes requires an analysis of the sediment transport on a river basin scale, as well as a historical tracing of the course of hydrotechnical works. Interesting information is provided by the lower Vistula river, where an unregulated section has been kept, there is a long section regulated in the 19th century and, since the 1970s, a reservoir supported by a barrage (Włocławskie Lake). Such differences in the degree of development make it possible to compare the influence of the river regulation on the transport of sediments and ice conditions.

History of Regulation works on the Odra river in the context of planned modernisation works

Until the 1830s, the Odra river was a river with little changed course, its regulation began after the catastrophic flood of 1736. The first works consisted in straightening the river bed with the use of cuts. These works led to an increase in the longitudinal gradient of the river at the places of cuts and erosion of the banks, while at the same time the accumulation of clastic material transported by the river began in the lower course of the river. The effect of sediment accumulation in the lower course of the Odra river was its running wild and branching of the river bed (Born, 1954). As the result of execution of cuts, the middle course of the Odra river (Nysa Kłodzka - Uraz estuary) was shortened by 22 km. The ease and low cost of execution of cuts was apparent as compared the high costs of stabilisation of the shortened new river bed. When in the second half of the 19th century this method of river regulation was assessed, it turned out that the cuts had more negative effects than positive ones.

The new methods of regulation of the Odra river were applied in the years 1819-1880 and they consisted in the application of systematic (carried out over a long distance) regulation with the use of double-sided groynes. The groynes were built as a wicker-and-ground structure designed by J.A. Eytelwein.

The breakthrough date for the regulation of the Odra river was 1819, when Prussia and Austria signed the so-called Bogumiński Protocol. The aim of this agreement was to reduce harmful cuts, preserve the winding route with gentle bends of the regulation route of the river and eliminate shallows in the current.

The regulation works began with a view to improve the navigation conditions in the periods of medium and low stages. The regulation works carried out in the first half of the 19th century in accordance with the Bogumiński Protocol produced positive results. By 1840 as many as 5432 groynes and 262 km of flood embankments were completed on the Odra river. The most intensive works on the Odra river were carried out in 1855-1874. In 1842, the management of the regulation works was taken over by C. Becker, who introduced the principle of building groynes based on sinking a fascine mattress loaded with stones, on which a superstructure was built only after the positive effects of the land formation had occurred.

The beginning of modern hydrotechnical works on the Odra river dates back to 1874, when the Directorate for the Construction and Regulation of the Odra river, based in Wrocław, was established. Its task was to organise the regulation of the Odra river in the section from Wrocław to Świecie. It was assumed that the minimum navigable depth of the Odra river bed should be 1 m. This assumption required a correction of the Boguminski Protocol of 1819, which established the minimum width of the river in its individual sections. In order to achieve the assumed navigable depth of 1 m with the mean water stage, the width of the river bed had to be narrowed by 20-25 m (Czaja, 2011).

In the years 1905-1913 near Ścinawa, Głogów, Krosno, supplementary experimental regulation works were carried out in order to get an answer whether it would be possible to reach the navigational depth of 1.3 m, and even 1.4 m by supplying from the reservoirs. The results were satisfactory, so after a break in the works caused by the war, the regulation was resumed in 1928, carrying them out until 1943. Fascine and stone groynes were used, inclined at the angle of 75^{o} against the current. By 1939, about 80 % of the intended regulation works were carried out. The supplementary regulation for low water stage covered the distance of 335 km, but in dry years it did not produce satisfactory results. In dry years, despite the discharges from the Turawa and Otmuchów reservoirs, it was not even possible to guarantee the depth of 1.2 m, and the interruptions in navigation lasted up to 3 months. (Muszyński, 1948).

After the World War II, the reconstruction of the damaged regulation structures began. The section of km 554 (Odra-Spree Canal) - km 667 (Odra-Havel Canal) was particularly untended, as before the war the main stream of loads bypassed this part of the waterway.

In the Lower Odra in the 1970s, in order to maintain the waterway, the water administration in Szczecin had to carry out dredging work with the average annual volume of 470 000 m^3. Crossovers occurred in those years in km 617 (at the mouth of the Warta river), km 623, 659, 662 (Miłkowski, 1976).

Contemporary use of the Odra river for shipping is limited mainly to the lower section, which will also be intensively used after the completion of the Niederfinow ship's hoist in Germany. This investment will facilitate the traffic of large vessels between the waterways of Berlin and Szczecin. The importance of the regulation structures on the Odra river has decreased in the context of water transport, but their role in improving the flood safety during the ice runoff has not changed. The regulation route eliminates branching of the current, large bed formations and eases the curvature of the bed. The movement of the current ice can be stopped by increased resistance caused by uneven river bed (outwashes, crossovers) or by a rapid change of flow direction (sharp bends of the entire river bed or bank line). When the current ice is stopped by the edge of the lake-type ice or increased resistance to its flow, a jam starts to form from the accumulation of current ice. Regulation structures are therefore an important element in reducing the risk of jam floods. In the event of occurrence of a jam and when the bed is made clear, icebreakers must be used for the ice run-off. This practice works well every year in the mouth of the Vistula river, in the lower section of the Odra river, on the Włocławskie Lake. Thus, maintaining the regulation buildings in a good condition is an important element of flood safety in the lower course of the main rivers in Poland. The proposed works in the Task 1B.2: Modernisation works on the border Odra river should be seen in the context of the overriding public interest, which is the flood safety. Since the middle of the 19th century, the Odra river has been subject to regulation work and canalisation, which means that we are now dealing with a river that has already been transformed by human. This means that the currently observed fluvial processes in the river bed are the resultant of hydrotechnical development and natural processes. Maintenance and improvement of the existing hydrotechnical facilities on the Odra river (similarly to the Lower Vistula river) does not constitute an interference with the natural river, because it was changed during the times of intensive shipping use as early as in the 19^{th} century. Inland waterway transport is now in the background, but the regulation buildings on the Odra also play an important role in the context of the flood safety.

Geomorphological effects of regulation

As a consequence of the regulation works, the lateral deformation of the river bed and the concentration of the stream are reduced. A river without the possibility of meandering and lateral erosion deposits the transported material in the fields between the groynes, forming a new floodplain. The regulation of rivers is carried out for the design flow corresponding to the mean long-term flow. The concentration of the water stream in the regulated bed creates conditions for better transport of the river load and leads to the filling of the space between the groynes with sediments. From the ecological point of view, the depth of the bed incision and the quantity of sedimentation on the new floodplain are important. Surveys of the quantity of the sediment deposition on the new floodplain of the upper Odra river were carried out by Czajka and Cieszewski (2010) in the Racibórz region. This section of the river was strongly changed at first as the result of cuts and then as the result of regulation works. The studies show that the current Odra river bed is about 3 m lower than the initial level, which is due to the cuts made in the 19^{th} century. The sedimentation resulting from these works on the new floodplain amounted to 1.3-1.8 cm/year, and currently it amounts to 2-5 cm. Geochemical analysis of sediments (heavy metals) was used to determine the rate of sedimentation, which enabled their dating in the vertical profile.

These data refer to the upper section of the Odra river, where the transport of suspended load and bed load is higher. The average water opacity of the Odra river in Miedonia is 166 g/m^3, and in Brzeg 109 g/m^3. In the further course it decreases quickly and amounts to 70 g/m^3 in Ścinawa, and in the lower course in Gozdowice to only 6 g/m^3. In terms of transport volume of the suspension, the difference between the lower course of the Odra river and the upper course of the Odra river is clearly visible. The denudation rate in the Chałupki profile is 70.7 t km^2/year and decreases to 3 t km^2/year in the mouth of the Odra river. The canalised section of the Odra river (sedimentation) as well as the change in the properties of the river in its lower course contribute to the decrease in transport. In the longitudinal profile of the Odra river between the Chałupki section and the estuary, the increase in the transported sediment load is very small (0.33 million tonnes/year), despite a 12-times increase in the flow. The Warta river does not contribute to the increase in sediment transport in the Lower Odra river (Fig. 1) as its river basin has a denudation rate below 5 t/km^2 year (Brański and Banasik, 1996).

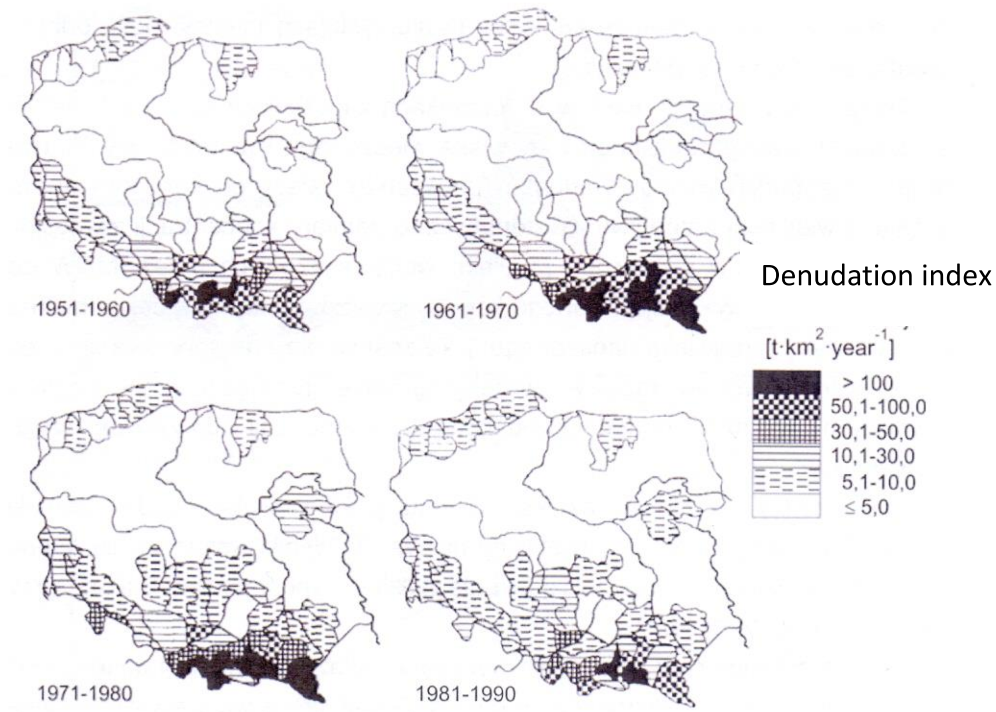

Fig. 1. Denudation index in the river basin of the main rivers of Poland (Brański and Banasik, 1996)

Comparing the transport conditions of the bed load in the Vistula and Odra rivers, it can be seen that the Vistula river transports twice as much of bed load per unit of water volume. The quantity of dragged bed load transport for the Odra river at the estuary can be estimated at 0.35 million t/year (Ciupa et al. 2017).

Heavy metals are used as a marker in studies on transport and deposition of river sediments, which allow to date sediments from the period of intensive industrialisation of the Odra river basin. The study by Ciszewski (2007) showed that as the result of sedimentation on a new floodplain forming since the first regulations, a layer of a few centimetres thick has settled in the

Lower Odra river (Fig. 2). Such a low rate of sedimentation on the floodplain of the Lower Odra river results from a small stream of sediments transported by the river.

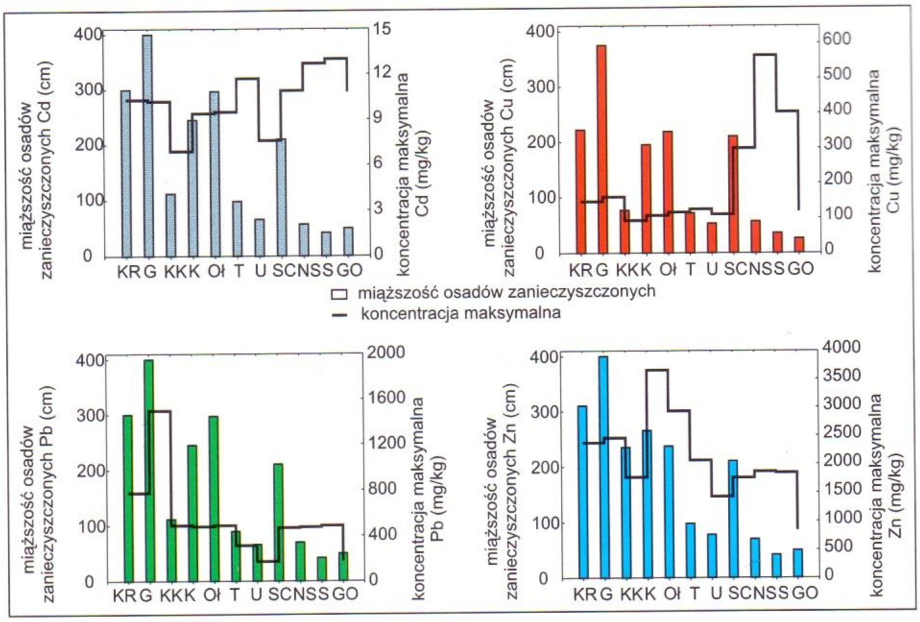

Fig. 2: Thickness of sediment layers on the Odra floodplain determined on the basis of heavy metals concentration: GO - Gozdowice profile (Ciszewski, 2007)

Key to Polish descriptions:

Miąższość osadów zanieczyszczonych - thickness of contaminated sediments

Koncentracja maksymalna – maximum concentration

As the result of the constructed hydrotechnical structures and with the current transport intensity of sediments, the Odra river has reached the state of equilibrium of the bottom, which is confirmed by cumulative results of the bottom deformation on the basis of observations made by the BfG since the 1960s. In their assessment, the Odra river reached a stable seabed level in 1998-2008 (Gerstgraser, 2018).

Also, the measurements of the rate of sedimentation of sediments contaminated with heavy metals indicate that the bottom of the Lower Odra river is stable and does not decrease, while a small sedimentation takes place on a new floodplain (Fig. 3). Ciszewski (2007) showed that despite the narrowing of the Lower Odra river bed as the result of the executed regulation works, this had not led to any significant lowering of the river bed in historical times and there had not been a strong sedimentation on the surface of the floodplain. Referring to these results, it can be assumed that a slight narrowing of the Lower Odra regulation route will not lead to significant deformations in the river valley, and the regulation works will only level the bottom.

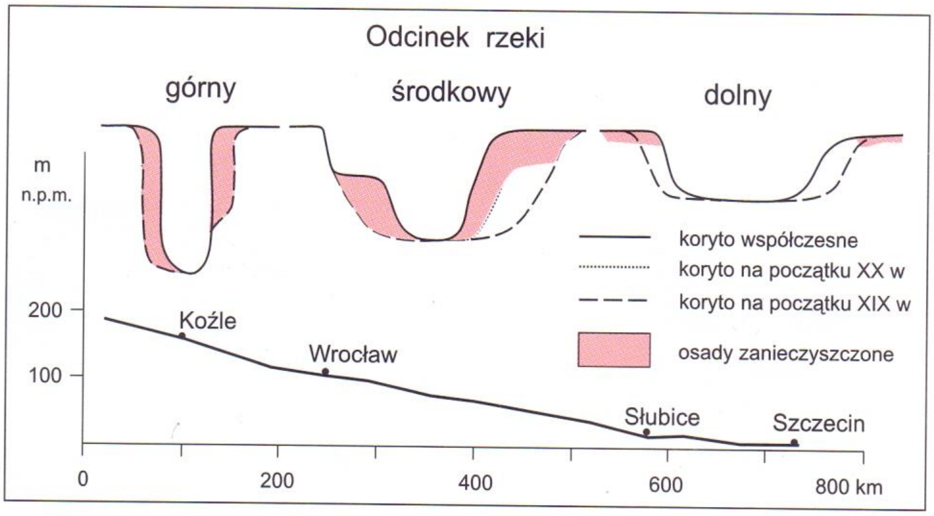

Fig. 3: Diagram of deformation of the Odra river bed and floodplain in its longitudinal profile determined on the basis of the analysis of sedimentation of sediments contaminated with heavy metals (Ciszewski, 2007)

Key to Polish descriptions:

Odcinek rzeki – river section
Górny - upper
Środkowy – middle
Dolny – lower
Koryto współczesne – current bed
Koryto na początku XX w – bed at the beginning of 20th century
Koryto na początku XIX w – bed at the beginning of 19th century
Osady zanieczyszczone – contaminated sediments

Bearing in mind the small volume (compared to the Vistula river) of the bed load transported in the Lower Odra river, one should not expect land formation in the spaces between the groynes, large erosion of the material already deposited on the new floodplain, and significant increase of ordinates of the floodplain. Similar conclusions are reached by the authors of the study (Analysis of results..., 2018), which used 2D hydrodynamic modelling for the section of km 613.8 - 616.1, covering the Warta-Odra estuary.

The authors of the report (Gerstgraser, 2018) write about the difficulties which, after the modernisation of the regulation structures, may cause an increase in the height of forms of bed streaks (dunes) migrating across the entire width of the river bed. They refer to the calculation of the ratio of tangential stress τ to the critical tangential stress for setting in motion the sediment grain τ_{cr} according to the Shields diagram. The formula for calculating the tangential stress τ was not given. The Du Boys equation is used in the national engineering practice:

$$\tau = \rho \cdot g \cdot h \cdot I$$

where:

τ – tangential stress in N m^{-2},

ρ – water density 1000 kg m^{-3},

g – gravitational acceleration in m s^{-2},

h – water depth,

I – longitudinal slope.

If the data from the Table 3 (Gerstgraser, 2018) for km 618 is used, the tangential stress calculated by the Du Boys formula is τ = 7.76 N m^{-2}

The Meyer-Peter and Müller equation used for the Polish rivers to determine the ultimate conditions of grain movement has got the form of:

$$\tau_{cr} = 0.047 \cdot (\rho_s - \rho)\ g \cdot d_{50}$$

τ_{cr} – critical tangential stress in w N m^{-2},

ρ_s – grain density of sediment 2600 kg m^{-3},

ρ – water density 1000 kg m^{-3},

g – gravitational acceleration in m s^{-2} ,

d50 – relevant grain diameter in m.

Again, taking the data from the Table 3 for km 681, the value of tangential critical stress τ_{cr}=0.59 N m^{-2} will be obtained. The ratio τ/τ_{cr} = 7.76/0.59 = 13.2, which according to Raudkivi means conditions of transport dominance in the suspension. Therefore, there can be no increase in the steepness and height of streaks (dunes) as the authors of the study write (Gerstgraser, 2018). Increased tangential stress acting on the bottom will flatten the bed forms and consequently level the bottom, which is beneficial for the ice flow and icebreakers' operation.

Another disputable assumption from the paper (Gerstgraser, 2018) is the assumption that we are dealing with two-dimensional dunes in the Odra river bed. Such forms are characteristic for experiments in hydraulic laboratories, however in rivers the picture of the bottom is more complex. The crossovers form in sections with too straightened river bed layout, at low river stages as the result of erosion of lateral shoals. The river, which is subject to regulation by straightening up the river bed and the development of groynes, still tends to follow the winding course of the current and the development of lateral shoals, between which crossovers extend. Such a picture of the bottom is confirmed by Fig. 22 from the study (Gerstgraser, 2018), where the forms typical for a regulated river such as shoal, crossover, and stream pool are visible.

In a regulated river, the main problem is the migration of lateral shoals, which cause the current to shift and the emergence of crossovers that hinder navigation. The higher tangential stress and the transition of sediments in transport from traction to the suspension obtained as the result of the modernisation of regulation structures will have a positive effect on the levelling of the bottom in the regulation route.

Groynes maintained in good condition and modernised equalise the distribution of velocities in the bed are important for maintaining the transit depth in the bed (important for ice-breakers), but also do not allow for large deviations of the current from the regulation route, which poses a risk of erosion of the banks and formation of a secondary bed with water flowing at the base of the embankments. Such a phenomenon is very dangerous for the stability of embankments, because a stream of water of high velocity directed diagonally to the bank flows underneath their base during flooding.

The proposed reconstruction of the groynes will result in narrowing of the regulation route, and the soft profile of the groynes will give a more equalised velocity profile, with less potholes behind the heads of the groynes, which should be considered as a positive phenomenon for equalising the velocity field and concentration of the water stream in the main current.

Influence of modernisation of the regulation structures on hydrological conditions

The Lower Odra river is characterised by a large valley retention, which is manifested by the flattening of the culmination of flood waves. A relative index that allows to compare the flood potential of rivers of different river basins is the *k* index proposed by J. Françou (Rodier & Roche, 1984). The higher the value of the flood potential index *k*, the greater the capacity of the river basin to create floods. In order to normalise the values in the equation, the maximum ultimate flow of 106 m^3/s and the maximum limit river basin surface area of 10^8 km^2 for the world's rivers have been assumed. The formula for the *k* index has got the form of:

$$k = 10 \cdot (1 - \frac{\log WWQ - 6}{\log A - 8})$$

where:

WWQ – the highest observed flow,

A – river basin in area w km^2.

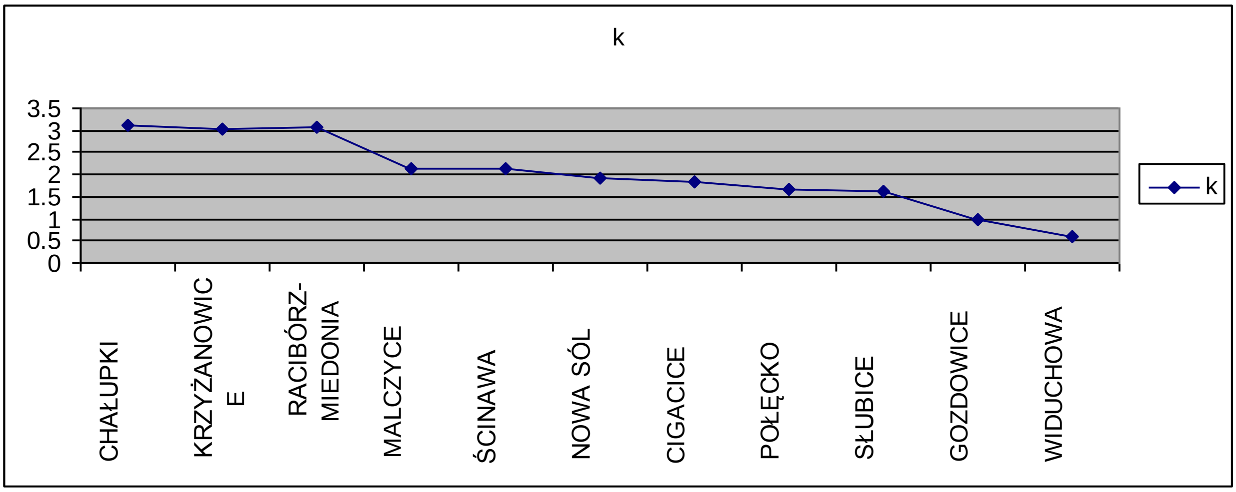

Fig. 4 Changes in the flood potential index in the Odra river longitudinal profile

As can be seen from the diagram (Fig. 4), the Warta river, despite its large share in the area and the flow of the Lower Odra river, does not affect the increase of the flood potential in the lower course of the river. The Odra river from the Słubice water level gauge profile shows a very low flood potential compared to other rivers in Poland (Fig. 5).

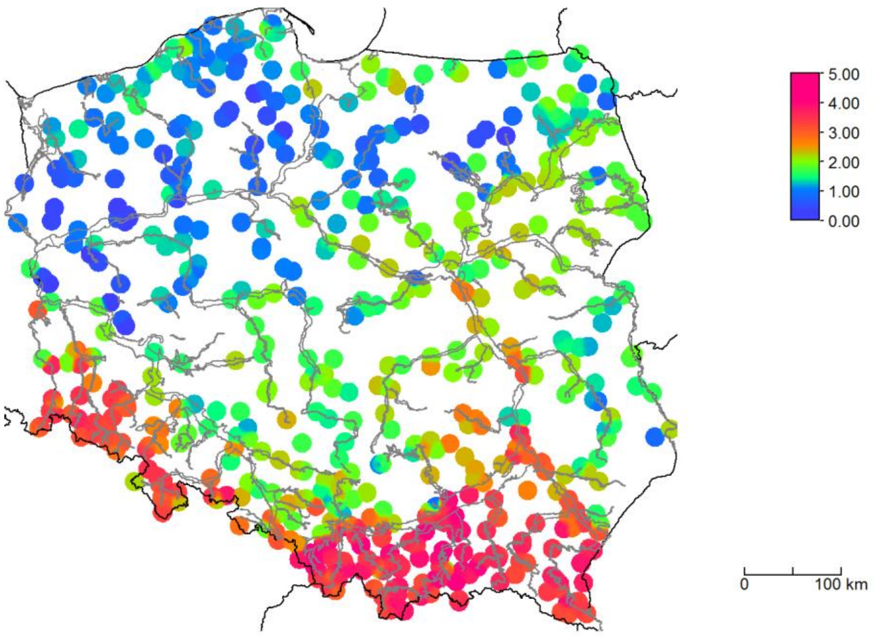

Fig. 5 Flood potential index of rivers in Poland (Magnuszewski and Porczek, 2015)

Modernisation of regulation structures on the Lower Odra river will not influence the flow conditions of freshets as these structures are designed to regulate the hydraulic conditions of mean and low flows. The results of hydrodynamic modelling (Analysis..., 2018) indicate that as the result of the modernisation of regulation structures, the increase in the mean water level will be about 20 cm – this is a small value in comparison to the changes in the position of the bottom of the Odra river that took place at the beginning of the regulation works, when the bed was shortened by means of cuts. The increase in the mean water level results from the concentration of the water stream by the modernised regulation structures. High flows above SWQ = 900 m^3/s, as well as low flows below SNQ = 100 m^3/s, will be uplifted by a negligently low height of 5-10 cm. It should also be taken into account that levelling the bottom of the Odra river as the result of the regulation may improve its hydraulic capacity, which will eliminate the effect of uplift and restore the current relations between the water level and the flow rate.

The issue of refuges for wintering fish, such as potholes at the bottom of the river near the heads of groynes, raised in the study (Gerstgraser, 2018), is disputable. The wintering fish avoid contact with flowing slush ice in winter, which can damage their bodies and then cause diseases in the warm season. High velocities of water flow also occur in the area of potholes near the heads of the groynes, which are detrimental to the energy expenditure of the fish during the wintering period.

The Lower Odra river belongs to the sections where ice jams occur with high intensity on practically every kilometre of the river (Fig. 6). It is a process, which is influenced by storm backwaters from the side of the Szczecin Lagoon and the ice cover of the lake type forming on the Lake Dabie and on the Szczecin Lagoon. The example of the lower Vistula regulation shows that the narrowing of the width of the river and the concentration of the flow stream affect the formation of the ice cover and the course of its disappearance. Pawłowski's research (2015) shows that after the regulation of the lower Vistula, ice jams were several times less frequent in comparison to the unregulated section. The hydraulic conditions in the lower section of the regulated Vistula river resulted in the decrease in the frequency of ice cover formation. As the result of changes in the morphometric and hydraulic parameters of the Vistula river bed, the risk of floods was reduced in the period of 100 years after the end of the regulation, which was also influenced by the possibility of using ice-breakers (Pawłowski, 2017).

The shortening of the ice cover duration in the regulated section can be noticed by comparing the regulated section of the lower Vistula river (profiles of Toruń, Korzeniewo, Tczew) with the section with a limited degree of regulation in the middle Vistula (Table 1).

Table 1: Duration of permanent ice cover on the Vistula, Bug and Wieprz rivers based on the study by Golek (1964)

River	Profile	Formation and disappearance of the ice cover		Duration of the ice over	
		beginning	END	Average	maximum
Vistula (Wisła)	Zawichost	31.12	10.03	30	92
	Puławy	13.01	10.03	35	95
	Warszawa	15.01	18.03	20	90
	Płock	8.01	9.03	25	96
	Toruń	9.01	16.03	14	81
	Korzeniewo	15.01	21.03	17	82

	Tczew	13.01	15.03	17	95

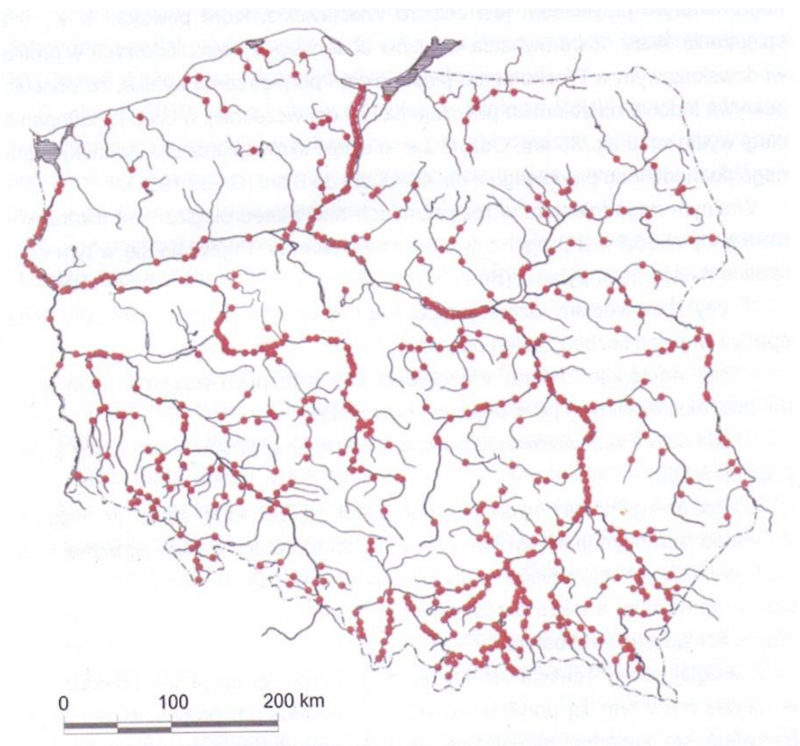

Fig. 6 Places of occurrence of ice jams in rivers in Poland (Grześ and Pawłowski, 2006)

The authors of the study (Gerstgraser, 2018) suggest replacing icebreakers with other vessels that could operate locally to remove ice jams. It should be remembered, however, that the ice jam removal consists in the construction of an ice-free trough, through which the ice masses accumulated in such a place could be floated. A similar situation also occurs at the mouth of the Vistula river to the Gulf of Gdańsk near Świbno and in the reservoir at the Włocławek barrage.

In the long term, changes in the hydrological conditions as the result of climate changes should be taken into account. This particularly applies to the duration of the ice phenomena - according to Pawłowski (2017), the increase in the average winter temperature observed since the 1960s in the perspective of 2030 will shorten the duration of the ice phenomena on the Vistula river by 5-10 days. The forecasts of climate changes in the perspective of the middle of the 21st century in the context of changes in navigational conditions on the rivers in Germany (KLIWAS, 2009) mention an increase in the flow of rivers in the winter period and, at the same time, a decrease in flows in the summer period. This puts into question the profitability of cargo shipping, e.g. on the Odra river, however the problem of ice jams does not disappear and will still require the intervention of icebreakers in the estuary sections of the rivers. In the climate change scenario, it can be expected that prolonged summer low water will continue until the beginning of the ice phenomena. The reason for the increase in the depth and duration of the low water will be the changed climate conditions with higher precipitation deficits in relation to the evaporation. Such a situation is dangerous because the insufficient volume of water in the river bed during the inflow of slush ice increases the chances of a jam formation.

Conclusions

In connection with the project planned to be implemented, after completion of the investment works, can the groundwater position be expected to change, will the existing groundwater levels be maintained, moreover, can the drainage of water from the areas surrounding the bed be expected to change?

The planned regulation works will lead to the alignment of the river bed geometry by narrowing the cross-section, into which the heads of the groynes of low inclination angle will gently enter. This will result in the disappearance of potholes at the ends of the regulation structures, so there will be no deep local scouring of the bottom, and hence the groundwater drainage base in the immediate vicinity of the river will not be lowered either. The regulation works on lowland rivers raise concerns that lowering of the river bed and the low and mean water levels will dry out the adjacent meadows. An example of the extent of such an impact is the study on the impact of the water level in the Narew river below the Dębe barrage on the groundwater in adjacent terraces, carried out by Kardasz and Simoni (1966). The data used in that paper were collected by the Institute for Land Reclamation and Grassland Farming and the archival materials of the State Hydrological and Meteorological Institute were used. These observations date back to the hydrological years of 1960/61 and 1961/62 from 95 groundwater stations in 22 cross-sections of the Narew and Bug valleys. On the basis of the curve of the groundwater table system constructed for the section below the mouth of the Bug river into the Narew river, the zones of groundwater dependence on the river waters were distinguished. It was shown that groundwater in the zone distant from the river by 0-200 m had reacted most strongly to changes in the water level in the river. In the case of the planned works consisting in the modernisation of the regulation structures in the Lower Odra we know, on the basis of model tests, that such deep deformations of the river bed, as took place in the 19th century, will not occur. The location of the groundwater in the zone adjacent to the Odra river will be influenced to a greater extent by the regional hydrogeological conditions and the amount of their feeding by precipitation in conditions of a changed climate than the changes in the water level in the Odra river caused by the regulation.

Can the functioning of the reconstructed regulation structures, both in the perspective of 40 years of spontaneous deepening of the river and after that time and reaching the objective, i.e. the depth of 1.8 m, cause changes in the current hydrological regime of the river, and if so to what extent and on what scale?

The regulation of the river will not affect the hydrological system of the Odra river, which is dependent on the supply and outflow conditions of the catchment. The Odra river has little potential for flooding and improving the condition of the regulation structures will contribute to the improvement of the flood safety by reducing the risk of formation of ice jams.

At the stage of functioning of reconstructed groynes, dams and bank protections, i.e. up to 40 years and later, can there be a change in flows, the length of stagnation of water on freshets and the force of deposition of alluviums by high water?

The regulation structures will not affect changes in flows or the ability of the river valley to flatten the hydrograph of flood waves. The volume of sediment transport, which depends on soil erosion processes and the supply of sediments from other sources on a river basin scale, will not change either. The small amount of river sediment transported in the lower course of the Odra river will not cause significant sedimentation on the floodplain and will not hinder both flooding and drainage of areas adjacent to the river.

Will the current dynamics of water stages be ensured, including annual and extreme low water as well as extreme freshets if the main current is concentrated in the central part of the river bed, will the areas directly adjacent to the river during low water be more dried up than so far?

The regulation structures (also modernised) do not influence the change in hydrological conditions on the river basin scale. Climate changes, which may manifest themselves in prolonged periods of drought, will be a greater problem on the regional scale. The results of bottom ordinate survey indicate stabilisation of the longitudinal profile of the river. In the paper by Nowicka et al. (2015) it was been shown that the impact of lowering the bottom of the Odra river as the result of strong erosion below the Brzeg Dolny barrage on the location of the groundwater was limited to the zone located closest to the river bed. Further away from the river, the groundwater levels are influenced by the water supply and flow conditions in the saturation zone.

Is it possible that in the long term perspective, during the functioning of the reconstructed regulation structures, the land-formation in inter-groyne fields can take place through acceleration in erosion and changes in the sediment accumulation processes?

Can the functioning of the reconstructed regulation structures result in the removal of sandy shallows within the inter-groyne fields?

The quantity of sediments transported by the Odra river is small compared to the Vistula river. If we take the Lower Vistula as an example, the space between the groynes has not been filled with sediments. There are still places of water circulation in the downstream part with the backward current and places where sandy sediments accumulate. Similar mechanisms work in the Odra river as similar regulation systems have been applied on both rivers.

Ciszewski (2007) also raises an important aspect of maintaining regulation structures in the Odra river in a good condition, i.e. protection of the Szczecin Lagoon against sediments polluted with heavy metals deposited in inter-groyne fields. These sediments, if they are immobilised and are not subject to transport in the river, do not pose a risk. Their movement could be possible under conditions of discontinuation of maintenance and modernisation works on regulation structures in the Odra river bed.

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